of 575° the white crust will disappear as the salt which made it has melted and mixed with the rest of the bath. This clearly shows that it is time to take the piece out of the bath and allow it to cool. This method can be used for tempering above 575° and below 900°, but is not practical for higher or lower temperatures owing to the alteration in the salt of which it is composed.

Another method that is used considerably on some classes of work is sand tempering. This consists of covering the work with sand, and heating both up at the same time. Clean and well-dried sand is sometimes used in a pan, and the metal heated up in it over a fire. Some special gas furnaces have also been built for sand tempering in which the sand is permanently kept at the required temperature. The work is placed in this until it has thoroughly attained the temperature of the sand, and then cooled in the air. Continuous operating automatic gas furnaces have also been made for sand tempering. In these the work and sand travels through the furnace, from one end to the other, by the aid of a worm. The work is then dumped out, while the sand is brought back to the other end, inside of the furnace, by means of a second worm.

A gas furnace, with a revolving retort, that is used for tempering is shown in Fig. 137. The outer shell of the furnace is lined with fire-brick, and this is heated by the gas. The round retort, the opening of which is shown at the end, is placed inside of the outer shell, and revolves on 4 wheels, two of which are at each end of the furnace. It is revolved by means of bevel gears, sprockets and chains, and a pulley and belt. The whole is mounted on trunnions, and can be tilted to any angle so the work will travel through the furnace automatically. This furnace is also used to give metal parts a gun-metal finish. This color can only be given to pieces that will stand tempering to 600° F., as it takes that temperature to put the color on the metal; this being done by means of charred bone and chemicals.

CHAPTER XII

CARBONIZING

METHODS AND MATERIALS USED — EFFECT OF ALLOYING MATERIALS AND HEAT TREATMENT

MANY of the steels that give very high figures in their strength tests are made hard enough to resist wear for such parts of machinery as gears, cams, ball races, etc., by hardening and tempering; but when the proper degree of hardness is obtained to reduce wear to a minimum, they are too brittle to withstand shock strains.

For this reason case-hardening, carbonizing, or, as it is called in Europe, "cementation," is resorted to, as by this process the outer shell can be made hard enough to resist wear, and the core of the piece can be left soft enough to withstand the shock strains to which it is subjected. By this method gears can be made from some of the special alloy steels that will reduce the wear to a point that would have been considered impossible a few years ago, and at the same time resist shock to such an extent that it is very difficult to break out a tooth with a sledge hammer.

Several methods different from the old established one of packing the metal in a box filled with some carbonizing material, and then subjecting it to heat, have been devised in the last few years. Among them might be mentioned the Harveyizing process which is especially applicable to armor plate. This in turn has been followed by an electrical and a gas process, which claim to be great improvements over the Harveyizing process. Very recently another process has been invented which uses gas for carbonizing in a specially constructed furnace. This is very useful for carbonizing small work.

The Harveyizing process uses a layer of charcoal between two plates which are heated in a pit furnace by producer gas. The weight of the upper plate brings the charcoal in close contact with the surfaces and facilitates the soaking in of the carbon.

This process has been a great success, but it also has its faults, as the carbon soaks in to a good depth in some places, while at other places, sometimes only a foot away, the carbon will not be so deep, so that when tested a shot will glance off from one spot, and when it hits a short distance from this will tear a great hole in the plate. Then again the Harveyizing process is not suitable for small work.

Electricity has also been used in a like manner to gas in the Harveyizing process. That is, armor plate has been covered with a layer of ground bone, the whole enclosed and a current of electricity turned on to heat the bone and metal so that the carbon will combine with the steel in a surface layer of desired depth, and it is claimed for this process that the depth can be regulated, and the carbonization is even over the entire surface.

As these two processes are only used on armor plate or other large work of a similar character, and are too expensive in their installation to be made applicable to parts of machinery, or tools, they will not be gone into in detail here.

The Krupp process is similar to the above two in the kind of work it operates on, and differs from Harveyizing in that it uses a gaseous hydrocarbon to replace the bed of charcoal. This also is foreign to the subject, but the gas it uses is practically the same as that used in the furnace for carbonizing with gas, which will be described later.

FACTORS GOVERNING CARBONIZING

The result of the carbonizing operation is determined by five factors, which are as follows: First, the nature of the steel; second, the nature of the carbonizing material; third, the temperature of the carbonizing furnace; fourth, the time the piece is submitted to the carbonizing process; fifth, the heat treatment which follows carbonizing.

The nature of the steel has no influence on the speed of penetration of the carbon, but has an influence on the final result of the operation. If steel is used that has a carbon content up to 0.56%, the rate of penetration in carbonizing is constant; but the higher the carbon content, in the core, the more brittle it becomes by prolonged annealing after carbonizing. Therefore it is necessary that the carbon content should be low in the core, and for this reason a preference is given to steels containing from 0.12 to 0.15% of carbon for carbonizing or case-hardening purposes. Some, however, prefer a steel containing from 0.20 to 0.22% carbon, owing to its being more easily worked with machine tools; but the results will not be as good as with a steel containing a maximum of 0.15% carbon. Greater strength and easier working qualities can be obtained by the addition of such alloys as chromium, vanadium, titanium, nickel, etc.

Manganese. — It is also very important that the manganese content of carbonizing steels be kept low. This should never exceed 0.35%, as manganese has a tendency to render the hardened and carbonized surface brittle, thus making it liable to chip and break at the least shock. Thus manganese is usually kept down to 0.20%, and seldom exceeds 0.25%.

Chromium. — While chromium has a tendency to produce a mineral hardness in steel, it prevents the development of the crystalline structure under heat treatment, thus refining the grain and making it better able to withstand shocks. Therefore chromium added in small percentages makes steels for carbonizing more homogeneous, and imparts to them greater strengths and wearing qualities. Chromium, however, produces steels that are very difficult to machine; it is therefore combined with other ingredients which offset this, except for such uses as armor plate.

Vanadium, used in homeopathic doses, overcomes this difficulty of machining chrome steels to such an extent that it is claimed that a steel containing 1% chromium and from 0.16 to 0.18% vanadium, can be forged and machined as easily as a 0.40% carbon steel. Vanadium also produces high dynamic strengths, which gives the core of carbonized steels a high resistance to shocks.

Titanium produces practically the same results as vanadium in steels for carbonizing, and is usually used in percentages of from 0.40 to 0.50.

Nickel, added to ordinary carbonizing steel in comparatively small percentages, obviates the brittleness which is usually produced by carbonizing, and makes it more homogeneous, the pearlite being distributed much better. With 2% of nickel, the steel is increased in strength; in some cases this strength is nearly double that of the ordinary carbonizing steel, but 2% nickel steel means nothing unless the carbon is of the proper percentages. When it is, it makes one of the best of steels, when carbonized and tempered, for such parts as shafts, ball races, gears, etc. It should therefore be used wherever the 2½ cents difference in price does not make it prohibitive, except where the higher price alloy steels are demanded, owing to their greater strength and wearing qualities.

A 2% nickel steel carbonized so that the surface layer contains about 1% of carbon will be pearlitic, but a 7% nickel steel will show a surface layer that is martensitic, with a pearlitic core. Martensite being a constituent of quenched steel, a 7% nickel steel carbonized so the surface layer contains 1% of carbon has the came constitution as an ordinary carbonizing steel that has been carbonized and hardened, that is, a pearlitic core and a martensitic outer shell. This martensite should become denser and denser as it approaches the outer surface. This will give high strengths, and the outer layer will readily polish without wear, thus giving it valuable wearing qualities.

This simplifies the processes of carbonizing, owing to its doing away with the hardening processes afterward, but the carbonizing and the cooling afterward must be carefully done in order to get good results from this process. If, however, the proper carbonizing materials are used, the heat of the furnace regulated so that it remains steady and at the proper temperature, and the piece not cooled too quickly, a saving in time and expense can be made with this process of carbonizing, when this grade of steel is suitable.

The influence of the different elements on the speed of penetration of the carbon, when carbonizing steels containing the same amount of carbon and different percentages of manganese, chromium, nickel, tungsten, silicon, titanium, molybdenum, and aluminum, is shown by Table 3.

Table 3.—Penetration of Carbon Per Hour

Component of Alloys	Speed of Penetration Per Hr. in Inches	Component of Alloys	Speed of Penetration Per Hr. in Inches
0.5 per cent. manganese.....	0.043	1.0 per cent. silicon.......	0.020
1.0 per cent. manganese.....	0.047	2.0 per cent. silicon.......	0.016
1.0 per cent. chromium	0.039	5.0 per cent. silicon.......	0.000
2.0 per cent. chromium	0.043	1.0 per cent. titanium.....	0.032
2.0 per cent. nickel.........	0.028	2.0 per cent. titanium.....	0.028
5.0 per cent. nickel.........	0.020	1.0 per cent. molybdenum.	0.036
0.5 per cent. tungsten.......	0.035	2.0 per cent. molybdenum.	0.043
1.0 per cent. tungsten.......	0.036	1.0 per cent. aluminum....	0.016
2.0 per cent. tungsten.......	0.047	3.0 per cent. aluminum....	0.008
0.5 per cent. silicon.........	0.024		

The rate of penetration for ordinary carbonizing steel under the same conditions would have been 0.035 inch. Thus it will be seen that manganese, chromium, tungsten, and molybdenum increase the rate of penetration. These seem to exist in the state of a double carbide and release a part of the cementite iron.

Nickel, silicon, titanium, and aluminum retard the rate of penetration — 5% of silicon reducing it to zero — and these exist in the state of solution in the iron. The titanium steel, however, has more titanium in it than should be present in carbonizing steel, and if this were reduced to 0.50% the results might be different. As it is, the 1% of titanium only very slightly retarded the penetration.

As a general rule the alloyed steels that give the best results in annealing, hardening, and tempering are not the best for carbonizing; for this reason most of these alloyed steels are made in a special grade for carbonizing. As an illustration of this, vanadium steel that gives the best results for crank-shafts, transmission shafts, connecting rods, and other moving engine parts is composed of 0.25 to 0.30% carbon, 0.40 to 0.50% manganese, 1% chromium, and 0.16 to 0.18% vanadium, while the best carbonizing steel has from 0.12 to 0.15% carbon, 0.20% manganese, 0.30% chromium, and 0.12% vanadium.

CARBONIZING MATERIALS

The nature of the carbonizing materials has an influence on the speed of penetration, and it is very essential that the materials be of a known chemical composition, as this is the only way to obtain like results on the same steel at all times.

These materials or cements are manufactured in many special and patented preparations. The following materials are used for carbonizing purposes: Powdered bone, wood charcoal, charred sugar, charred leather, cyanide of potassium, ferrocyanide of potassium, acid cleaned animal black, anthracite, graphite, horn, acetylene, petroleum gas, naphtha, carbon monoxide, illuminating gas, and gasoline. In addition such materials as black oxide of manganese, barium carbonate, ammonia, and others are used in mixture with the preceding substances.

Such materials as bone and leather should not be used alone as it is impossible to obtain definite results from them, owing to the changeability of their chemical composition when subjected to a temperature high enough for carbonizing.

Wood charcoal is very largely used in carbonizing steels, but the value of this material varies with the wood used, the method employed in making the charcoal, and other factors. Used alone it gives the normal rate of penetration for the first hour, but after that the rate gradually decreases until at eight hours it gives the lowest rate of penetration of any of the carbonizing materials.

The best wood charcoal is that made from hickory. This is due to the fact that this charcoal contains a relatively high percentage of carbonate of potassium, and this, in conjunction with the charcoal and the nitrogen of the air, in the carbonizing box, is capable of giving cyanide of potassium. Thus, by combining wood charcoal and carbonate of potassium, an increase in the rate of penetration can be obtained; but this speed decreases with time, due to the volatilization of the alkaline cyanides. If a current of ammonia is used, the rate of penetration becomes constant, as cyanide of ammonium is formed. Therefore some consider the best carbonizing materials to be the ones that produce the most of this substance.

Powdered charcoal and bone give good results as a carbonizing material and are successfully used in carbonizing nickel-chrome steel, by packing it in a cast-iron pot and keeping this at a temperature of about 2000° F. for four hours, and then cooling slowly before taking the metal out of the pot or removing the cover.

Pure carbon, such as that of sugar, does not carbonize in vacuum; therefore a carbonizing material that is simply composed of carbon can only act directly by solution of the carbon, starting with the iron in contact with it. Thus sugar should be mixed with some other material in order to obtain the best results from carbonization. Carbonic oxide, giving $2CO = C + CO_2$, which is formed by the action of the air, in the carbonizing box, on a carbonizing material that is composed simply of carbon, may act; but its action is slow, and the carbonic acid, CO_2, has a decarbonizing action.

Materials containing a cyanide act by means of the cyanogen radical $(CN)_2$. This compound is decomposed, giving up its carbon to the steel. In some cases a small amount of cyanide appears to act as a carrier of carbon from some other substance to the steel. Ferro-cyanide of potassium heated gives cyanide, cyanate of potassium, and oxide of iron. A mixture of ferro-cyanide and bichromate of potash gives rise to a new mixture of cyanide and cyanate diluted in a mass of iron and chromium oxide. Carbonate of barium, under certain conditions and in the presence of the nitrogen of the air, gives rise to cyanide of barium according to the following equation: $2N + 4C + CO_3Ba = (CN)_2Ba + 3CO$. Therefore it acts by means of cyanide and carbonic oxide.

Certain carbonizing materials contain carbonates that are dissociable at the temperature of carbonization, especially calcium carbonate. In the presence of carbon there is formed carbonic oxide, which carbonizes very slowly.

Therefore the carbonizing materials might be classed as follows: First, cements which act by means of carbonic oxide; second, cements which act by means of a cyanide, such as potassium, barium, or ammonium; third, cements which act by means of hydrocarbons. To carbonize with the hydrocarbons, it is necessary to generate the gases and conduct these to the receptacle in which the work has been placed in such a manner that they may carbonize the pieces before passing out of the vent.

J. C. Olson and J. S. Weissenback, at the Polytechnic Institute in Brooklyn, made some tests on carbonizing, with gases. They used $\frac{3}{8}$ inch soft Norwegian iron that contained 0.08% of carbon, and the results are best shown in Table 4.

TABLE 4.—RESULT OF EXPERIMENT OF CARBONIZING STEEL WITH GASES

Test Number	Gas Used	Time in Hours	Hardness	Depth of Case, Inches	Carbon Content, Per Cent.
1	Illuminating and ammonia (*a*)......	4	glass	0.004	0.57
2	Illuminating and ammonia (*b*)......	4	glass	0.008	0.66
3	Illuminating and ammonia (*c*)......	4	glass	0.008	0.91
4	Illuminating......................	4	none	none	none
5	Illuminating and ammonia (*a*)......	8	glass	0.012	1.12
6	Illuminating and ammonia (*b*)......	8	glass	0.012	1.16
7	Illuminating and ammonia (*c*)......	8	glass	0.012	1.15
8	Carbon monoxide and ammonia (*c*)..	4	glass	0.016	1.45
9	Carbon monoxide................	4	glass	0.016	1.36
10	Acetylene and ammonia (*c*)........	4	glass	0.012	0.98
11	Acetylene........................	4	little	not well defined	0.41
12	Methane and ammonia (*c*)........	4	little	not well defined	0.32
13	Methane.........................	4	little	not well defined	0.26

The ammonia was used in different strengths *a* being the weakest with *b* twice the strength of *a* and *c* twice the strength of *b*.

From the results shown in this table the conclusions were drawn that ammonia gas facilitates the case-hardening in all cases except that of carbon monoxide, which seems to act almost as well without as with ammonia. Of the three pure gases studied, the carbonizing ability is in the following order: Carbon monoxide, acetylene, methane. The illuminating gas not being a pure gas and varying in composition with the different gas companies, it cannot be given a fair comparison with the other gases. With illuminating gas and the strongest ammonia the 4-hour test showed a very good percentage of carbon, and in the 8-hour test the percentages of carbon ran about equal in all of the three different strengths of ammonia.

The results obtained from carbon monoxide show it to be by far the best gas for this purpose, and the difference in the carbon percentage between carbon monoxide alone and carbon monoxide combined with the strongest ammonia was so slight that it does not seem necessary to use ammonia with it. In the case of carbon monoxide the gas was freed from carbon dioxide by bubbling through strong caustic potash solution before entering the case-hardening tube. Roughly speaking, the hardening depth is for the four hours proportional to the time.

NITROGEN. — The commonly used carbonizing materials all contain nitrogen in some form or other, and as the non-nitrogenous materials cost from one tenth to one-twentieth of those containing nitrogen, some experiments have been made with anthracite and coke. After carbonizing the same sized test pieces with these for four hours at 1650° F., the penetration for the anthracite was 0.006 inch, and with the best grade of hard coke it was 0.0064 inch. Charred leather under the same conditions gave a penetration of 0.062 inch. As this was in the proportions of 10 to 1 it would lead to the conclusion that nitrogen performs an important part in carbonizing.

The effect of ammonia was also tried by carbonizing in a gas pipe, and packing the work in sugar charcoal as the non-nitrogenous material. Dry ammonia was passed into one end of the gas pipe, and allowed to flow out through a small vent hole in the other end. The results obtained by carbonizing for four hours at 1650° were 0.058 inch for the charred sugar alone, and 0.070 inch for the charred sugar which had ammonia passing through it. The non-ammonia specimen was bluish-black in color, and when sawed appeared soft, while the ammonia-treated specimen was of a distinct whitish luster, and appeared to have a tough outer skin when sawed.

Thus all the evidence goes to prove that nitrogen aids carbonizing in practical work, and whether present in organic form or as ammonia it acts as a carrier of carbon, probably through the formation of small traces of cyanides.

The speed of penetration caused by the action of different cements at different temperatures for the same time, *i.e.*, eight hours, is best shown by Table 5.

TABLE 5

Temperature in Degrees Fahrenheit	MATERIALS USED AND RATE OF PENETRATION IN INCHES			
	Charcoal 60 per cent. + 40 per cent. of Carbonate of Barium	Ferro-cyanide 66 per cent. + 34 per cent. of Bichromate	Ferro-cyanide Alone	Powdered Wood Charcoal Alone
1300	.....	.....	.....	.....
1475	0.020	0.033	0.020	0.020
1650	0.088	0.069	0.079	0.048
1825	0.128	0.128	0.128	0.098
2000	0.177	0.177	0.198	0.138

The nature of the carbonizing materials has a very pronounced effect on the rate of carbonization, or the percentage of the carbon content in the surface layer of the piece, or both.

At the same temperature, *i.e.*, 1825° F., for different lengths of time and with different cements, the rate of penetration obtained was according to Table 6.

TABLE 6

Length of Time in Hours	MATERIALS USED AND RATE OF PENETRATION IN INCHES				
	Carbon 60 per cent. + 40 per cent. of Carbonate	Ferro-cyanide 66 per cent. + 34 per cent. of Bichromate	Powdered Wood Charcoal Alone	Charcoal and Carbonate of Potassium	Unwashed Animal Black
1	0.031	0.033	0.028	0.059	0.035
2	0.039	0.037	0.053	0.078	0.059
4	0.047	0.049	0.063	0.094	0.088
6	0.078	0.074	0.072	0.011	0.106
8	0.118	0.128	0.098	0.138	0.128

Eighty per cent. charcoal + 20% carbonate of barium, 40% charcoal + 60% carbonate of barium, ferro-cyanide alone and 66% ferro-cyanide + 34% bichromate were used with practically the same results for eight hours' time.

Another set of tests was carried out for a longer period of time, with other materials and at a uniform temperature of 1650° F., with the results given in Table 7.

TABLE 7

Length of Time in Hours	MATERIALS USED AND RATE OF PENETRATION IN INCHES		
	Charred Leather	Ground Wood Charcoal	Barium Carbonate and Wood Charcoal
2	0.045	0.028	0.055
4	0.062	0.042	0.087
8	0.080	0.062	0.111
12	0.110	0.070	0.125

The test bars in this table were 3 inches long and $\frac{1}{4}$ of an inch square. The chemical composition of the steel was as follows: Carbon, 0.14%; manganese, 0.58%; silicon, 0.01%; sulphur, 0.08%, and phosphorus, 0.03%.

These tables show that charcoal when used alone gives the slowest rate of penetration, but when combined with other materials the rate of penetration is the highest of any of the tests made. In some cases the rate of penetration of the combined materials nearly doubles that of the wood charcoal alone.

EFFECT OF TEMPERATURE

The degree of carburization of the skin depends largely on the degree of temperature maintained during the carbonizing process; therefore it is necessary that the temperature be kept at a definite point in the carbonizing of steels. This can best be done by attaching to the furnace something to gage the heat, such as a pyrometer. If the temperature is too high, the metal is liable to crystallize and the core will rapidly become brittle. And if too low the rate of penetration will be low. The temperature to which the metal can be safely raised in carbonizing varies with the kind of steel used. As a general rule the ordinary carbonizing steel cannot be raised to a temperature in excess of 1800° F. If the original carbon content is high, even this temperature cannot be safely reached, while with some of the alloy steels, such, for instance, as nickel-chrome steel, a carbonizing temperature of 2000° can be retained for four hours without the core crystallizing, and the rate of penetration will be reasonably high, providing, of course, that the original carbon content is low.

The temperature, however, must be kept above 1300° F., as ordinarily carbonization cannot take place below that point, although in an experimental way steel has been carbonized at about 850° by using a mixture of cyanide of potassium, chlorides of the alkalies, and the alkaline earths, the latter being used to lower the fusion point of the cyanide.

The percentage of carbon which is absorbed by the steel is also affected by the temperature as well as by the materials used. With a given depth of penetration and a given amount of carbon in the carbonizing material, steel will absorb a greater percentage of carbon at a high temperature than at a low one.

HEAT TREATMENT AFTER CARBONIZING

The heat treatment following carbonizing should be very carefully done owing to the fact that the piece must have a very hard outer surface to resist wear, and a non-brittle core that will resist strains; also, some methods of heat-treating have a decarbonizing effect, and some of the steels have a tendency to produce cracks or fissures and to warp. Thus crank-shafts for internal-combustion engines were formerly carbonized and hardened, but owing to the difficulty of preventing cracks and warping this practice has been abandoned.

As a general rule the piece should be annealed after carburizing. This can best be done by leaving it packed in the carbonizing case, with the cover fastened on, and allowing it to cool gradually; but if the carbonizing temperature is not over 1600° F., it can be allowed to cool to 750°, then reheated to 1400°, and quenched with good results. If the carbonizing temperature is a high one, *i.e.*, above 1800°, the piece should be allowed to cool, then reheated to 1650°, and quenched and reheated again to 1400° and quenched.

The reason for the double quenching is that the piece must be heated to above its point of transformation, *i.e.*, 1650°, to destroy the crystallization and consequent brittleness, which is liable to be in the core when it is carbonized at a high temperature; but this leaves the carbonized surface layer not hard enough to resist wear, therefore it must be quenched again at 1400°. This point of transformation varies with the different components of the high-grade alloy steels, and this should be ascertained before hardening the piece.

By quenching directly from the carbonizing retort a distinct line is formed between the high-carbon outer shell and the low-carbon cone, and this is liable to cause the metal to crack on this line when the work is used for parts similar to rollers in roller bearings, owing to the wearing and crushing strains to which they are submitted, but if the work is properly heat-treated after carbonizing, this distinct line is made to disappear, and the danger of the steels cracking there is removed.

Aside from the above rules, the general rules should be followed that are laid down for annealing, hardening, and tempering, in their respective chapters.

TIME OF EXPOSURE

The time that the work is submitted to carbonizing is an important factor, as the regulation of this under a given constant temperature is what gives the depth of carbon desired, and by the proper depth of the carbon is obtained the percentage of carbon desired in the surface layer. The percentage of carbon in a carbonized piece of steel gradually reduces from the outer shell to the core. The lower the carbonizing temperature, the less the time of submission to the carbonizing temperature, and the smaller the percentage of carbon in the carbonizing material the greater will be this reduction.

A round bar of steel that was carbonized to the depth of $\frac{3}{16}$ of an inch was examined by turning off $\frac{1}{16}$ of an inch, and analyzing the turnings for carbon, then another sixteenth was turned off and analyzed, and the third and fourth sixteenth treated in a like manner. This gave a carbon content of 1.24% for the $\frac{1}{16}$ of an inch taken from the outside, the second sixteenth gave 0.85% carbon, the third sixteenth showed 0.24% carbon, and the fourth or core contained 0.13%.

The time of submission required for a certain depth varies with the kind of carbonizing materials as well as with the process used. The carbonizing materials, such as powdered bone, charcoal, etc., which require that the work be packed in an iron box or other receptacle, take considerable more time to carbonize the work than when gases are used to furnish the carbon, owing to the necessity of the heat penetrating the box and carbonizing materials before it can affect the work. In case a deep penetration of the carbon is required, and the carbon in the carbonizing materials is nearly or entirely absorbed, it is a difficult operation to insert fresh materials in the packing box.

Another point might be mentioned here, and that is that all steels do not retain their carbonization. One specimen was examined by taking a very thin cut from the outer surface for a part of its length, which on analysis showed 1.25% of carbon. The piece was then laid aside for six months, and a similar cut taken from the rest of its length, which on analyzing showed only 0.92% of carbon. This showed that the carbon dissolved little by little into the mass.

CARBONIZING WITH GAS

In the use of hydrocarbons, or gases, a fresh supply can be kept flowing into the carbonizing receptacle, and the time greatly reduced for deep penetration with an appreciable reduction of time for the shallow penetrations.

A very important factor in carbonizing with gas is the furnace, as on the design and operation of this to a large extent depends the success or failure of the process. They are designed specially for this purpose, and are, therefore, not practical for use as hardening, annealing, or tempering furnaces, although they might be made useful for annealing or hardening large quantities of work by being fitted with appliances for handling the same.

This makes the cost of installation higher than for the appliances used for carbonizing in the old way. The cost of carbonizing, however, is about one-half of that of the old method, which makes the furnace soon pay for itself by the saving in materials and labor. Where the cost of carbonizing is reduced to this extent it makes it commercially practical to carbonize steel parts that were considered prohibitive by the high cost and non-uniform results of the old method. Owing to the nature of the process of carbonizing by the old methods it is very difficult to obtain uniform results with pieces packed in the same box, or to repeat these results in other boxes.

In order to judge the temperature of the pieces packed in a box it is necessary to insert test wires through the cover. After a certain time a test wire near the outer edge of the box is withdrawn and the temperature is found to be just right for carbonizing, but if one is drawn out of the center of the box at the same time it will be seen that the temperature here has not risen high enough, as it takes a much longer time for the pieces in the center of the box to be raised to the proper temperature than for those near the outer surfaces of the box.

As the carbonizing material must be packed in the box with the pieces, this means that the pieces near the sides of the box will begin to absorb the carbon before those in the center, and, therefore, the penetration will be greater. As the percentage of carbon in the outer surface of the pieces being carbonized is greater the greater the depth of penetration, it also means that the pieces near the outside of the box will have a greater carbon content on their surface than the pieces in the center, and this also means that they will be harder.

Carbonizing with gas overcomes this to a large extent, if not entirely, as the carbonizing gas is not turned on until all of the pieces in the retort of the furnace have arrived at the proper carbonizing temperature, and it is shut off the minute the proper depth of carbonization has been obtained. The furnace can also be so regulated that the same results can be obtained with the next lot of pieces put in the retort. The carbon in the retort is also held constant by the steady flow of the gas, and the work can be inspected for temperature by shutting off the carbonizing gas and looking through the outlet pipe, where the work can be seen and its color noted.

A special furnace for the gas carbonizing process is built and patented by the American Gas Furnace Company, and is shown in Figs. 138 and 139. In Fig. 139, *A* is the retort in which the work is placed. This is made out of extra heavy 8-inch pipe, for the size of furnace shown, and is made to revolve on the rollers *B*, by the gear wheel *C*, and the worm *D*, which in turn is propelled by the sprocket wheel shown in Fig. 138. *E E* are air compartments to prevent the heat and work from getting into that part of the retort which extends beyond the heating furnace; *F* is the heating-gas chamber, the gas coming in through 5 openings or burners similar to the one shown at *G*, and exhausting out through others; *H* is the cover for the end of the retort, and is fastened on with hinged bolts and thumb screws. This is taken off in order to put the work in the retort, the partition *I* and carbonizing gas outlet *J* coming with it.

The heating gas is fed through pipes and burners on the side, and the carbonizing gas passes through the hose shown above the sprocket wheel in Fig. 138, and then into that part of the retort where the work is held. After the carbon has penetrated the metal the gas escapes through the outlet *J*.

In this process the carbonizing gas was vaporized from the liquids, naphtha and ammonia, and as the work is made to revolve in the furnace, similar to the action obtained by a tumbling barrel, an even depth of carbon is obtained on all sides of the work, and this overcomes, to a large extent, the tendency of carbonized pieces to have hard and soft spots, as the soft spots are usually caused by the piece coming in contact with something that would not allow the carbon to act on that spot.

Pyrometers can be attached to the furnace to gage the heat for the correct temperatures, and when this has been attained the valves and cocks can be set so that the work can be duplicated for any number of times and the furnace run for a long period with an assurance of the quality of the work turned out, as the temperature is held constant. Starting with a cold furnace in the morning, an hour and a half is usually required to get the work hot enough to absorb the carbon.

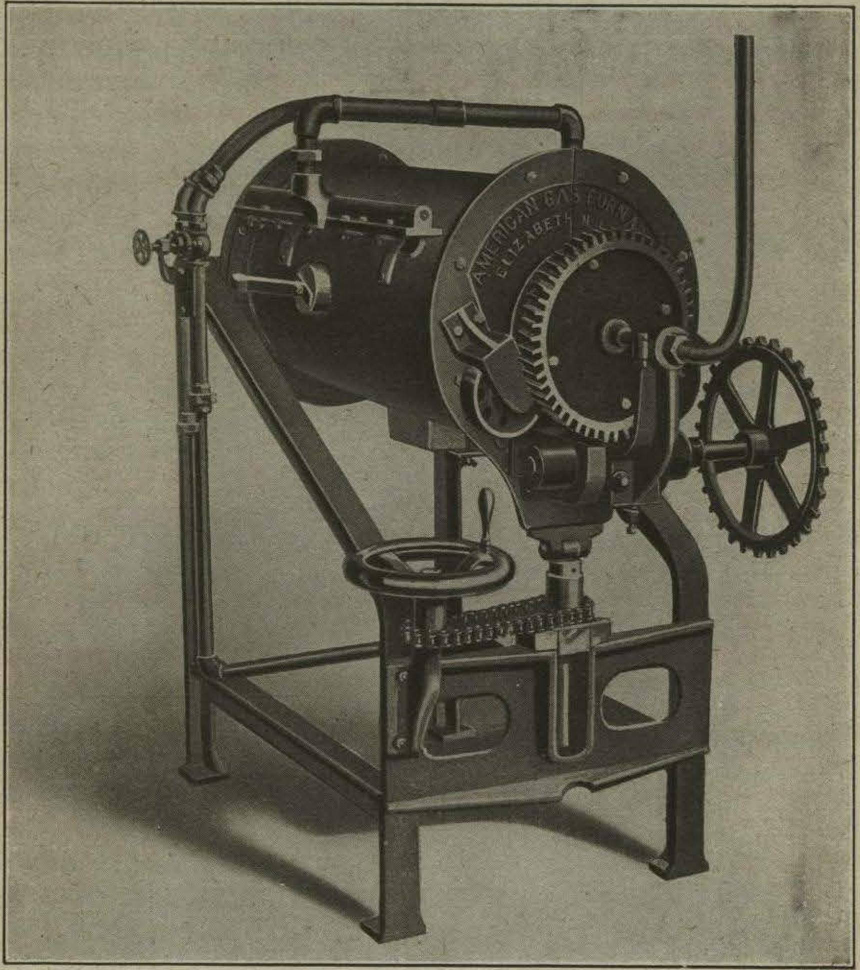

FIG. 138. — Revolving retort furnace for carbonizing with gas.

Odd-shaped and intricate pieces can be carbonized by this method

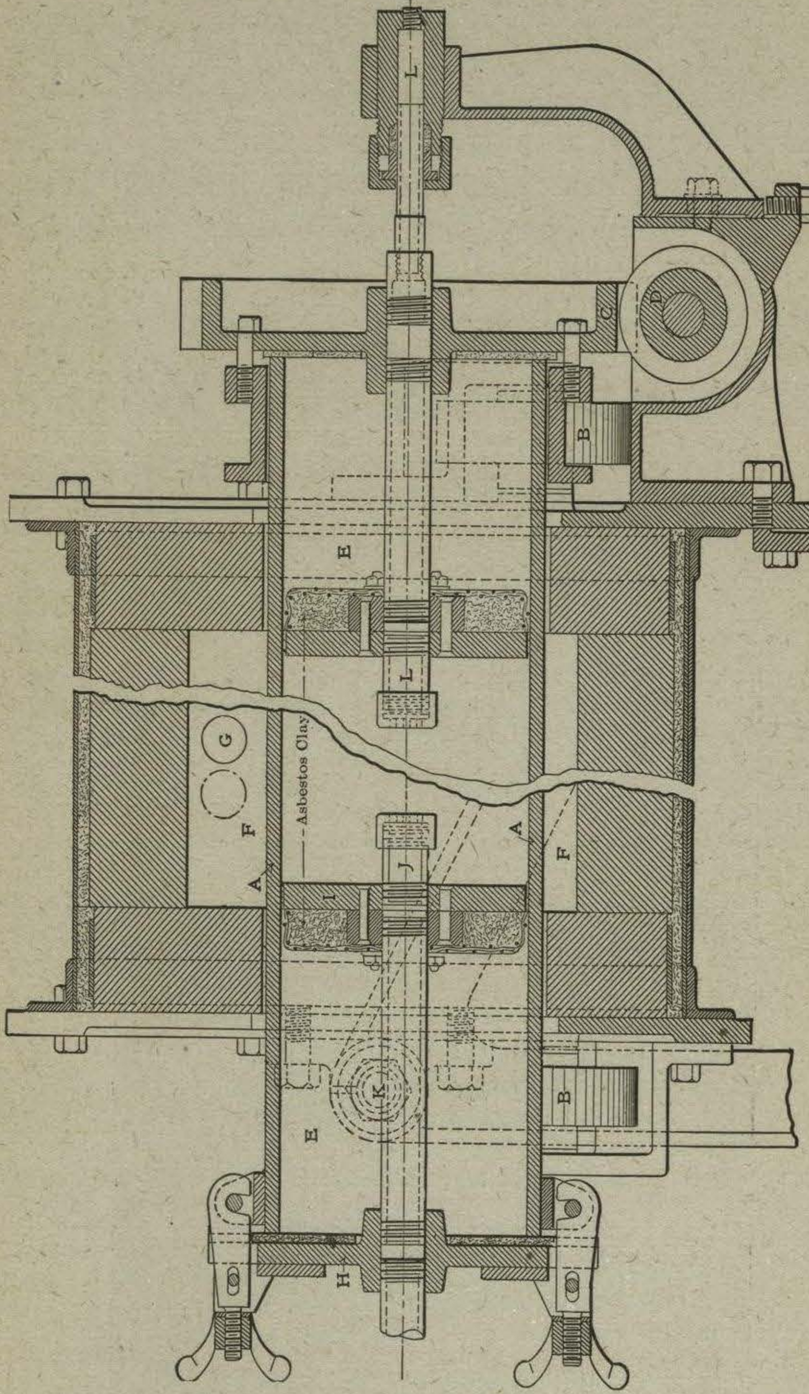

FIG. 139. — Sectional view of furnace for carbonizing with gas.

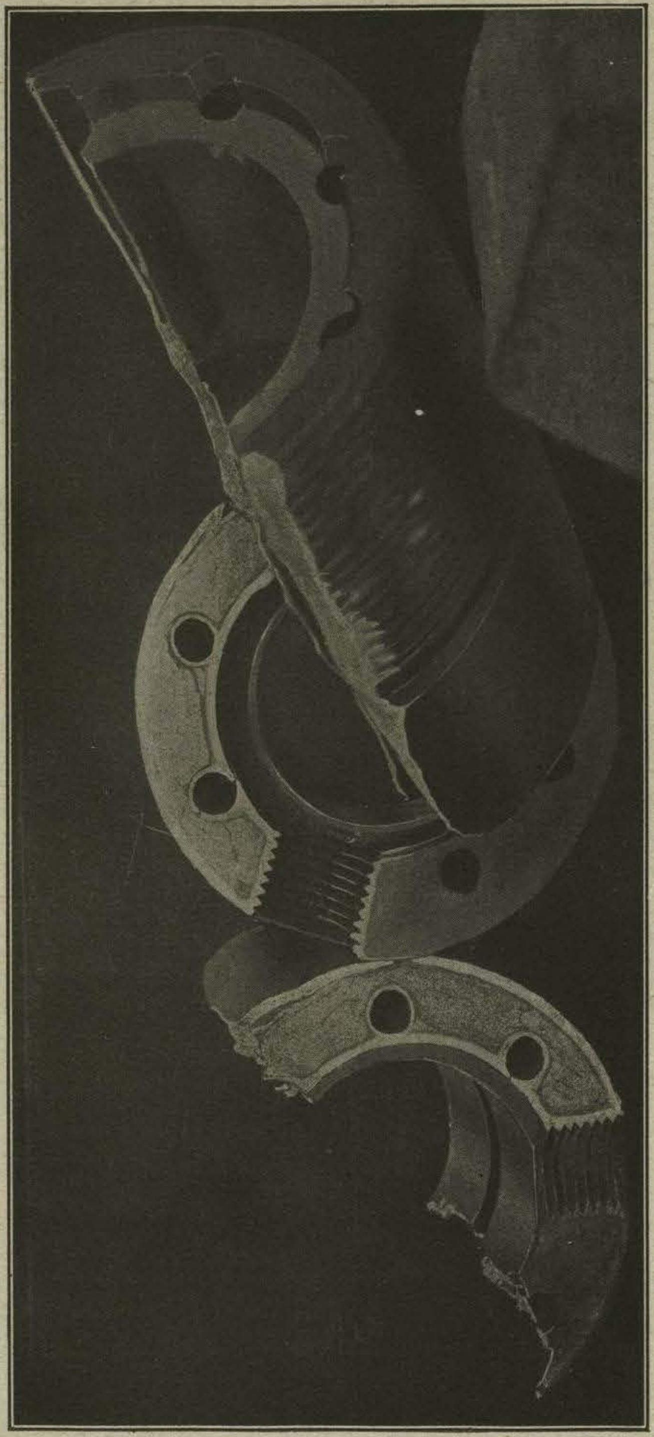

FIG. 140. — Difficult piece carbonized with gas.

that it would be difficult to do by packing in an iron box in such materials as bone and charcoal. This is best illustrated by the piece shown in Fig. 140 that has been broken open to show the action of the carbonizing gas on the seven small holes around its rim, and it will be seen by a glance at the half-tone that the carbon penetrated to a good depth all around these holes. The piece to the left shows the surface that was broken at a distance of about 4 inches from the end to the right. It also showed that the carbon had a good even penetration as to depth on all of its exposed surfaces both inside and outside.

The results of different lengths of time that the work is submitted to carbonization in this gas furnace is shown in Figs. 140 and 141. The distinct line between the carbonized shell and the core is obtained by plunging the metal directly from the carbonizing furnace into a quenching bath. By Fig. 141 is shown the depth of carbon that is obtained in this furnace by carbonizing for 4, 8, 10, 12, 14, and 16 hours, and then quenching in a lard-oil bath directly from the furnace. The test bars were $\frac{5}{8}$ inch in diameter, and are reproduced here at about their actual size. The results as to depths for this set of pieces is as follows:

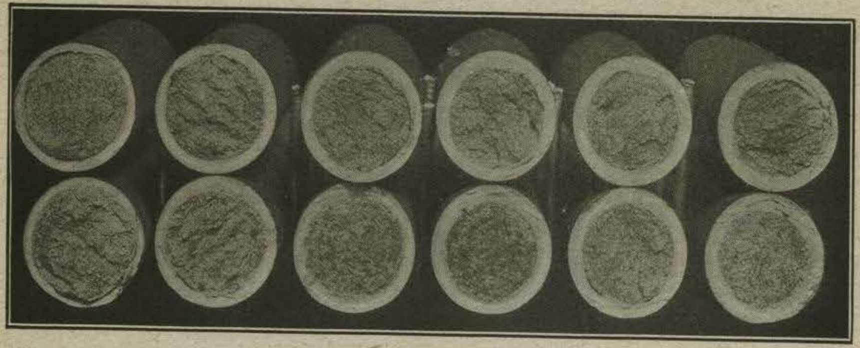

FIG. 141. — Quenched directly from the carbonizing furnace.

Time for Carbonizing in Hours	Depth of Penetration in Inches
4	0.040
8	0.062
10	0.071
12	0.079
14	0.085
16	0.090

The set of test pieces in Fig. 142 shows the depth of penetration for

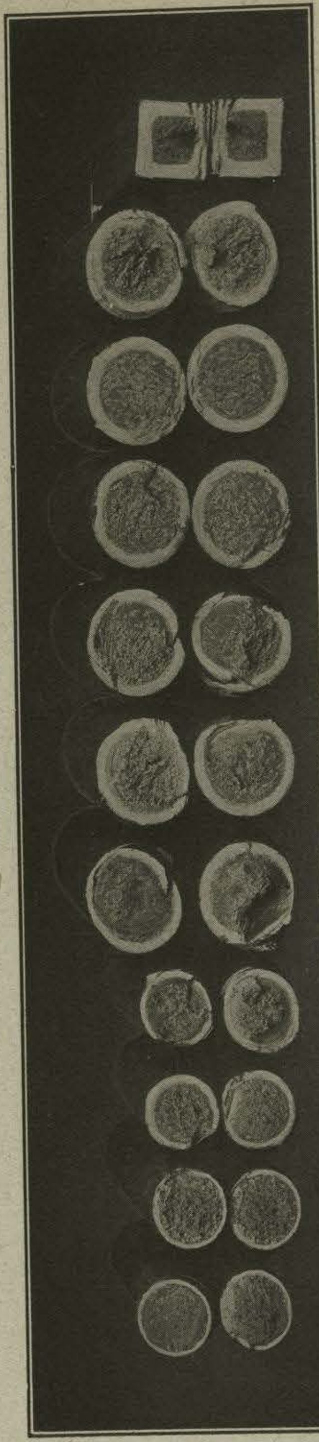

FIG 142. — Penetration of carbon each hour from one to nine.

each hour, from 1 to 9 inclusive, as follows, as well as the size and shape of the piece:

Time, Hours	Size of Test Piece	Depth in Inches
1	⅜ in. round	.015
2	⅜ in. round	.020
3	⅜ in. round	.030
4	⅜ in. round	.038
5	½ in. round	.046
6	½ in. round	.053
7	½ in. round	.056
8	½ in. round	.058
9	½ in. round	.060
9	½ in. round	.063
9	⅜ in. square	.075

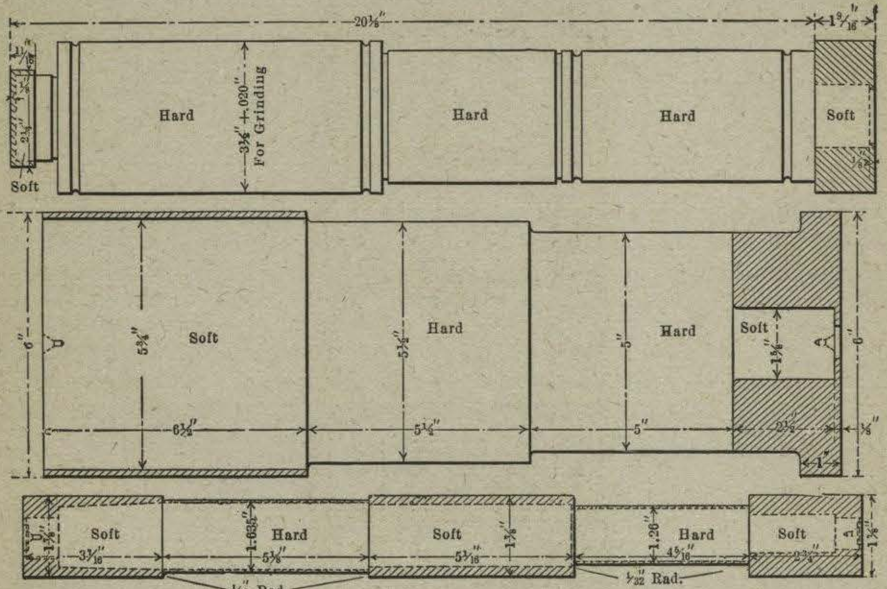

FIG. 143. — Samples of local hardening by carbonizing.

Intricate or peculiar-shaped pieces that would not turn over in the furnace, but slide around on the bottom, would have very little carbon on the side that remained in contact with the retort. For these it would be necessary to put something inside of the furnace so constructed that it would cause them to turn over. Delicate pieces that would be liable to break would also have to have some special apparatus inside of the retort to protect them.